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ABSTRACT

The superiority of males in mathematics achievement from grades eight through college is evident, and the following causes of sex differences in mathematics achievement are considered in the paper: spatial ability, enrollment in mathematics courses, social factors, anxiety, attitudes, and developmental differences between the sexes. Alleviating the differences is presented by addressing the need for females to study more mathematics, to improve in spatial visualization, to decrease math anxiety, and to overcome social factors which singularly and in combination hinder the mathematical achievement and advancement of females throughout their lives. Educators, parents and students must recognize the problem, understand the nature and causes of the problem, and then attack the problem from a multi-faceted perspective addressing both the needs of the students and the causes that have produced the existing differences in achievement. (Author)

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Improving Female Mathematics Achievement

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Abstract

The superiority of males in mathematics achievement from grades eight through college is evident, and the following causes of sex differences in mathematics achievement are considered in the paper: spatial ability, enrollment in mathematics courses, social factors, anxiety, attitudes, and developmental differences between the sexes. Alleviating the differences is presented by addressing the need for females to study more mathematics, to improve in spatial visualization, to decrease math anxiety, and to overcome social factors which singularly and in combination hinder the mathematical achievement and advancement of females throughout their lives. Educators, parents and students must recognize the problem, understand the nature and causes of the problem, and then attack the problem from a multi-faceted perspective addressing both the needs of the students and the causes that have produced the existing differences in achievement.

Improving Female Mathematics Achievement

The importance of mathematics achievement has become more evident in the 1980's when "whole ranges of occupations are off limits to those without a strong math foundation" (Sowell, 1982, p. 1). Some fields, such as engineering, sciences, and statistics have long been recognized as being highly dependent upon one's mathematical achievement; however, countless others, such as economics, education and other social sciences, and even agriculture have become much more mathematics dependent. Hence, educators have realized that more mathematics is needed in every day life and in many more careers and jobs.

Motivation to achieve in mathematics related to career options appears to be changing, since studies in the early 1970's and before indicated that males thought math was more useful to their career aspirations (Ernest, 1975; Hilton & Berglund, 1974; Maccoby & Jacklin, 1974); however, Fennema and Sherman (1977c) reported only slight sex differences among females and males in their perception of the usefullness of mathematics in their futures.

Motivations to achieve and suceed, abilities to develop skills and knowledge, and anxieties concerning specific subject matter areas affect the accomplishments of both males and females, and because of what seems to be differences in mathematics achievement between the sexes, the question of whether females are a disadvantaged group in the learning of mathematics must be addressed. When a female enters a male-dominated field of study in higher education, she must have already overcome the hurdles of "early stereotyping, peer influences, aptitudes, the absence of role models, parental

expections, and a number of other family and social factors" (Peng & Jaffe, 1979, p. 285).

The extent of sex differences in mathematics achievement, the causes of these differences, and suggestions for improving female mathematics achievement will be considered in this paper.

The Extent of Sex Differences in Mathematics Achievement

The results from research have indicated that the extent of sex-related differences in mathematics achievement ranges from tremendous to only slight. Fennema (1977) criticized the results from the National Assessment of Educational Progress for describing the sex-related differences in mathematics achievement as overwhelming, because she regarded this statement as an overgeneralization of the problem in which background and training were not considered.

There appears to be no difference in mathematical achievement in favor of boys among preschool and early school children (Callahan & Glennon, 1975; Campbell & Katrin, 1978; Fennema, 1973; Hilton & Berglund, 1974; Maccoby & Jacklin, 1974). Although differences in favor of girls have been found in the early grades (Aiken, 1974), differences in favor of boys begin to appear by grade six (Callahan & Glennon, 1975; Fennema, 1977). Jacobs (1978), Hilton and Berglund (1974) and Karnovsky (1974) found no significant differences in mathematical achievement in grade seven; however, differences in favor of boys appeared after grade seven. From grade eight through college, evidence supporting male superiority in mathematical achievement is plentiful (Astin, 1974; Brocklehurst, 1979; Campbell & Katrin, 1978; Fennema, 1974a; Fox, 1974; Jacobs, 1978; Krutetskii, 1976; Maccoby &

Jacklin, 1974; Michaels, 1978; Steel, 1978). Fennema (1977) found that males score higher on the math portion of the Scholastic Aptitude Test, and Fox (1976b) found this same pattern among gifted students with 7% of the males in that study scoring higher than any female.

Sex related differences in problem solving techniques and scientific thinking in relation to problem solving have been examined. Meyer (1978) concluded that males and females approach problem solving differently, using different intellectual processes. Witkin (cited in Hilton & Berglund, 1974) found that males tend to use a more analytical approach, which would lead to greater success. Wandelin (cited in Fennema, 1974a) concluded that males were more capable of translating words into math symbols and then processing them in a logical way, and Torrance (cited in Krutetskii, 1976) found that boys could generate more ideas and principles concerning scientific problems. However, Atweh (1980) noted that more low achieving males drop out of high school than low achieving females.

From evidence of the Study of Mathematically Precocious Youth, Benbow and Stanley (1980) concluded that sex differences in mathematical aptitude and achievement are a result of superior mathematical ability in males. The study extended from 1972 until 1976 and involved approximately 10,000 mathematically talented youth in grades seven through 10. Since mathematical curriculum is not elective through grade eight, differences could not be explained by differential course taking. Also, Benbow and Stanley claimed that attitudes and socialization could not account for the differences found in mathematical aptitude. Kolata (1980) reported that the conclusions made by Benbow and Stanley are very likely to be questioned and criticized.

Causes of the Differences

Spatial Ability

Theories hypothesizing that male superiority in the area of mathematics is an innate characteristic are usually expressed in relation to spatial ability. Spatial ability is frequently assessed by speeded tests in which an individual must decide about the identity of two-dimensional or three-dimensional figures by mentally rotating and comparing one or more figures in the comparison set (Pellegrino & Glaser, 1979). Other related tasks used to measure spatial aptitude include block design and assembly and mental paper folding in which individual differences exist in process speed, strategy for execution and the nature of the internal representation. Spatial ability is only one human ability contributing to general intelligence (Eysenck, 1979), and when Thurston (cited in Eysenck, 1979) emerged with a number of apparently independent primary factors or separate abilities, his conclusion was that there was no general factor of intelligence. Thurstone's primary mental abilities include spatial ability as well as reasoning, word fluency, verbal ability, numerical ability, and rote memory. According to Anastasi (1968), spatial aptitude corresponds to the S factor in Thurstone's primary mental abilities and to the k factor in the British hierarchical model of intelligence. Through factor analysis, spatial aptitude has also been found to have a high loading in many performance and non-language tests of general intelligence.

Males often excel in spatial abilities, and Guilford (1967) found them ahead in spatial orientation and spatial visualization. One might hypothesize, according to Guilford, that the male superiority could come about

because boys are more active, and by getting about more, they have more experience with space; however, if this were correct, then sex differences should appear before age five. Gesell, Halverson, Thomoson, Ilg, Castner, Ames, and Amatrude (cited in Guilford, 1967) reported in 1940 that no evidence of male superiority during the first five years was available. Thurstone (cited in Guilford, 1967) concluded that the space factor is differentiated by ages three to four, but this indicates nothing about sex differences at that age level. Stafford (cited in Guilford, 1967) provided some evidence that spatial ability is a sex-linked characteristic by indicating that spatial visualization plays an important role in most tests of mechanical aptitude.

> Kirmura (cited in Fincher, 1976, p. 267) speculated that most human evelution must have taken place under conditions where for the male hunting member of society accurate information about the immediate and the distant environment was of paramount importance. For the female, who presumably stayed closer to home with other non-hunting members of the group, similar selection processes may not have operated.

Treagust (1980) found that gender differences in spatial development are not manifest in the younger years but only in later adolescense. He contended that while gender differences can be individually accounted for by a personal-historical explanation, a genetic epistemological explanation can better account for the differences.

Biological reasons are presented as explanations for male superiority in spatial ability. Stafford (1972) hypothesized that spatial ability is

determined by a sex-linked gene. Another theory is that spatial ability is affected by hormones with the males usually having the amount conducive to this ability. A third theory concerns the laterialization of the brain. However, Luchins (1979) concluded that biological explanations are fruitless, the research inconclusive and further research would not be promising in this area.

Some theorists have attempted to explain spatial differences by referring to the different rate of brain lateralization between the sexes (Badger, 1981). Cerebral functions relevant to spatial perception are localized in the right hemisphere of the brain. These theorists have maintained that men's superior spatial performance is the result of a strong lateralization of the brain functions. Women's cerebral hemispheres are less specialized, and this lack of specialization interferes with their perceptual abilities (Levi-Agresti & Sperry, cited in Badger, 1981). Another group of theorists has argued the opposite ground indicating that men's superior spatial ability stems from a lesser degree of specialization and that girl's early verbal development results in a stronger localization of verbal functions in the left hemisphere and spatial in the right (Buffery & Gray, 1972).

Vandenburg (cited in Maccoby & Jacklin, 1974) indicated that spatial ability seems to be less influenced by educational and cultural factors than verbal ability, and the fact that spatial ability appears to be both highly heritable and different in mean level for the two sexes has suggested a genetic sex linkage. Since some women will have two space recessive genes, their genetic potential for spatial ability will be the same as that of men who have a single recessive space gene on the X chromosome. Spatial

ability, like all other human abilities, is genetically multidetermined (Maccoby & Jacklin, 1974).

Differences between the sexes have most consistently been found on tasks involving spatial visualization, which involves the visual imagery of three dimensional objects and the movement of those objects or their properties (Badger, 1981). In mathematical terms, spatial visualization requires objects to be rotated, reflected and/or translated. Not all spatial tests or items on spatial tests show significant differences between the sexes, but those differences that do occur are in favor of males. The tests of items that most consistently differentiate between the sexes are those that demand both three-dimensional thinking and kinetic manipulation of imagery. Boys almost invariably perform better than girls on items which picture piles of blocks in contrast to items involving paper folding (Badger, 1981).

Cross cultural studies have noted that sex differences on certain spatial tests (e.g. the Embedded Figures Test) appear only in highly stratified cultures in which males exercise strong authoritarian control over females, while less structured societies show little differences (Fairweather, 1976); however, Kabanova and Miller (cited in Fennema, 1974a) found no sex related differences in spatial ability among Russian or Eskimo children.

Sex related differences in visual-spatial test performance and mathematics achievement appear to emerge at about the same age (Maccoby & Jacklin, 1974). A few studies have indicated a difference in favor of boys in spatial ability in the early grades of elementary school (Maccoby, 1966; McDaniel & Guay, 1976). By the upper elementary grades and through adolescence, the differences favoring boys is evident (Astin, 1975; Burton, 1979;

Campbell & Katrin, 1978; DeWolf, 1977; Husen, 1967). However, Fennema and Sherman (1980) reported no significant difference in spatial ability among the high school students that were tested. Also, Sherman (1980) concluded from the retesting in 1979 of students from an earlier study that the males had increased only slightly more than the females in spatial ability. This inconsistency with data from earlier studies was attributed to the changing female role.

Research in this area is compounded by the fact that neither the domain of skills represented by the term visual-spatial ability nor the domain represented by the term mathematics achievement is unidimensional. Certain types of visual spatial skills may be related to certain types of mathematics problems; whereas, other types of visual spatial skills may be totally unrelated to any aspect of mathematics achievement (Connor & Serbin, 1980). Sherman and Fennema (1977) found differences in spatial ability in the schools where there were sex related differences in mathematics achievement, and according to Maccoby and Jacklin (1974), spatial ability is the most consistent area in which sex differences occur.

Fennema (1975) argued that spatial ability has two or more factors, and she concluded that male superiority exists on one type of ability, spatial visualization, with the difference not appearing until adolescence. Fennema also noted that the lack of empirical data confirming a positive relationship between mathematics achievement and spatial visualization fails to support the logical relationship between the two variables.

In a study by Kail and Siegel (1977), sex differences in the retention of verbal information and spatial information were examined. They concluded

that girls recalled verbal information more accurately and spatial information less accurately than boys. Werdelin (1958) found a spatial visualization factor positively related to a number or computational factor. This suggested that an emphasis on computation or number skills could interfere with the development of spatial visualization ability to the detriment of matematical reasoning. The possession of spatial skills may permit greater lattitude in dealing with a range of problems, since an excessive reliance on verbal strategy may hinder girls' flexibility in mathematical work (Badger, 1981).

The results of a study conducted by Connor and Serbin (1980) suggested that for girls verbal skills may play a more important role than visual skills in mathematics achievement, since the relationship between visual spatial skill and mathematics achievement was markedly less for girls. Those tests which were good predictors of mathematics among girls were all from the spatial visualization subdivision of visual spatial ability.

Although spatial visualization has been found to correlate highly with performance, this does not imply a causal relationship. The influence is a mutual one, for practice and experience in space related activities have been found to increase both mathematics and spatial scores. Yet girls, on the whole, do not participate in these activities, and their performance suffers as a result. Girls' marked decline in mathematics achievement at adolescence is casually linked to deficiencies in spatial ability (Badger, 1981). A lack of spatial ability forces girls to rely upon an inappropriate verbal strategy in attempting to solve certain problems (Werdelin, 1958), and since spatial tasks are considered more of a measure of innate ability than of achievement, it has been argued that girls' lower performance in mathematics

can be accounted for by their comparative lack of spatial ability. "The extent of the discrepancy in performance between the sexes may be contingent upon the degree to which mathematics is dependent upon this ability" (Badger, 1981, p. 14).

Enrollment in Mathematics

Fewer females than males elect to take advanced math courses in high school or continue to study math in college. This decline in female enrollment begins to occur in grade 10 when math classes become elective. Allen and Chambers (1977) found that approximately 50% of the students in Algebra I classes were females, but only 37% of the students in fourth year math classes were females. Haven (1970) reported that among high school seniors 56% of the girls were enrolled in math classes and 84% of the boys. Burton (1979) found that among Berkely freshmen 57% of the males had taken four years of math in high school, but only 8% of the girls had taken four years of math. Sills (cited in Kaminsky et al, 1976) reported that 92% of the females entering the University of California in 1972 were unprepared for calculus. The differences in enrollment between males and females continues to increase during college. Fennema and Sherman (1976) gave the following report of the math students at the University of Wisconsin-Madison in 1975. In the third semester math classes, males out-numbered females six to one. Of the 175 students that received bachelor degrees in mathematics, only 45 were females, and of the 179 graduate students in math, only 15 were females.

There are two theories regarding the enrollment in math classes. One explains the male superiority in mathematics as a result of females electing not to take advanced courses (Allen and Chambers, 1977; DeWolf, 1977; Fox,

1977; Fennema and Sherman, 1977a; Steel, 1978). The other theory claims that advanced math classes are populated more by males, because males have more mathematical ability (Benbow & Stanley, 1980). Reasons given for many females electing not to take advanced math courses other than lack of ability involve the social sterotyping of math as a male domain, anxiety toward math, lack of interest in math related fields, and attitudes toward math.

Mathematics achievement has long been recognized as one of the most important predictors of both election of mathematics and future mathematics performance (Sherman, 1979). Males, more than females, attribute success to ability, while females, more than males, attribute success to effort. The opposite is true for failure experiences, with females, more than males attributing their failure to the stable factor ability. Sex related differences which are found in studies of causal attribution are generally larger if the task or performance of interest is sex typed as masculine, as is mathematics (Fennema, 1977).

Pedro, Wolleat, Fennema, and Becker (1981) indicated that females who reported more anxiety or lack of confidence about mathematics were less likely to attribute their mathematics success to their ability and planned to study fewer semesters of high school mathematics.

Through young children do not necessarily think of math as an exclusively male activity, adolescents do, and Fox (1977) has suggested that girls may be discouraged from studying math, because they believe that males are prejudiced against women who do math related work. Male adolescents are more apt to find mathematics an inappropriate activity for girls than are teachers, parents, and others.

Motivation to achieve in mathematics as related to career options appears to be changing for females. Studies in the early 1970's and before indicated that males thought math was more useful to their career aspirations (Ernest, 1975; Hilton & Berglund, 1974; Maccoby & Jacklin, 1974). Fennema and Sherman (1977c) reported only slight sex differences among females and males in their perception of the usefulness of mathematics. According to Perl (1979), perceived usefulness of mathematics was shown to predict the election of mathematics courses of study in the National Longitudinal Study of Mathematics Ability.

Peng and Jaffe (1979) indicated that parents' education is positively related to women's enrollment in the high school academic programs, higher test scores, and higher educational plans, which, in turn, have positive relationships with women's entry in the male-dominated fields. For both men and women, high school curricular programs are not related to the entry into male dominated fields. However, entry into male dominated fields is related to science and mathematics course work in high school and test scores, probably reflecting the fact that more science and mathematics courses are offered in college preparatory programs. Women in men's fields are more work-oriented, and the value of work orientation is strongly related to choice of male dominated career goals which is consistent with the greater interest and financial reward associated with these jobs.

Boys' superiority in math during the high school years may simply reflect their greater interest in this area (Maccoby & Jacklin, 1974), which could be based on their greater expectations that they will need to use math for their later careers. Boys do tend to take more math courses when they

have a choice. During adolescence, boys' superiority in math tends to be accompanied by better mastery of scientific subject matter and greater interest in science. Since the two disciplines are closely linked, male superiority in science could be a derivative of greater math ability.

Perceived usefulness appears to be the variable having the strongest relationship with the mathematics plans for both sexes. Females and males who perceive mathematics as useful to them are more likely to persist in its study whether they are in algebra or geometry classes. Anxiety is found to be more highly correlated with the mathematics plans of males than those of females.

Males, more than females, elect advanced high school mathematics courses (Pedro, Wolleat, Fennema, & Becker, 1981). Even those males who are in the lower half of the achievement distribution are more likely than their female counterparts to continue the study of mathematics. This differential in the amount of mathematics taken has been cited as a major explanation of sex-related differences in adults' mathematics performance and in their participation in mathematics related careers (Fennema, cited in Pedro, Wolleat, Fennema, & Becker, 1981).

Girls' electing not to take advanced math courses are influenced by their perception of math as a male domain (Fennema, 1977; Husen, 1967; Michaels, 1978). Girls will avoid success in male dominated areas, and Fox (1975) concluded that girls drop out of advanced math classes because of fear of negative consequences.

The Male Domain

Social factors are probably the most supported explanations for sex-

related differences in mathematics. The root of almost all the social factors is the fact that math has been labeled a male domain, a prominent view in the American culture. Evidence of this can be found in the media, in textbooks and test items, and in the attitudes of parents, teachers, and students.

Parents begin to encourage sex appropriate behavior and discourage behavior that is not sex appropriate very early in a child's life (Burton, 1979). The kinds of toys parents buy for their children can have an influence on their mathematical development. Scientific and spatial toys are stereotyped masculine and not given to girls (Maccoby & Jacklin, 1974). Parents buy more mathematical games for boys (Reyes, 1979), and girls are encouraged to participate in homemaking activities, while boys are encouraged to build, push, and climb.

Aiken (1974) concluded that differences were a result of same sex modeling by children. Girls pattern themselves after their mothers, who more often express incompetence in math related situations. Rappaport (cited in Fennema, 19[illegible]) reported that mothers help their children more than fathers in all subjects except higher level mathematical subjects, which results in the reenforcing of math as a male domain (Vidal, 1976).

Kaminsky, Erickson, Rors, and Bradford (1976) found that parents provide a negative influence on daughters toward math, and Fox (1976b) found that even parents of gifted girls did not encourage them in the area of mathematics. Parents of students in grades nine through 12 perceived girls with less mathematical ability than boys (Kaminsky et al, 1976). In a study involving women mathematicians, Burton (1979) reported that these women

tended to come from homes that rewarded academic achievement. However, 17% of the women mathematicians who responded to a questionnaire reported that they had been discouraged by family and friends (Luchins, 1979).

Even at a young age, children will persist in activities they feel are sex-appropriate and will avoid activities they feel are not sex-appropriate. Burton (1978) reported that boys in grades two, six, and 12 rated math as the most masculine subject. Milton (1957) and Astin (1974) reported that persons who identify with the masculine sex role tended to have more problem solving ability.

During adolesence when sex role activities are well defined, mathematical differences usually begin to appear (Fennema & Sherman, 1977c). Mueller (cited in Dwyer, 1974) found that achievement motivation, attainment value, and expectancy of success were higher for sex appropriate tasks. Females do not achieve in mathematics, because it is not considered a sex-appropriate activity (Talcott, 1977). Sherman (1980) reported that the view of math as a male domain negatively affects girls' learning mathematics.

Boys are encouraged in math related fields more than girls not only by parents, but also by teachers (Ernest, 1975; Fox, 1974; Reyes, 1979). Teacher expectations affect achievement, and teachers expect boys to be superior in mathematics (Coulter et al, 1975; Ernest, 1976). Also, mathematics is a male dominated field in which most of the higher level math courses are taught by men (Fox, 1975; Goldman & Hewitt, 1976). Luchins (1979) claimed that teachers are not providing female role models, not encouraging females to enroll in math courses, and not making students aware of famous mathematicians.

Mathematics as a male domain is reenforced by textbooks, test items, and the media (Fox, 1976a). Research has shown that males are represented more often in textbooks in situations involving math (Weitzman & Pizzo, 1974). Males are depicted more often in progressional settings in which achievement is encouraged, and females are more often depicted in domestic settings (Burton, 1978; Fennema, 1974). Jennings (1975) found that children prefer stories with typical sex role behaviors, and Leder (1974) found that problem settings had an effect on problem solving. Christopolos (1978) found that the sex orientation of problems has an effect on the ability to solve problems. These conclusions extend to test items, which have been found to be more male oriented (Dwyer, 1976). Glennon, Calhoun, Jarvis, and Maccoby (cited in Schonberger, 1978) claimed that much of the apparent sex differences would be eliminated if the sex biases were eliminated from test items.

Hilton and Berglund (1974) claimed that sex typed interests affect mathematical achievement. They found that boys read science books and magazines and talk more about math and science more frequently than girls. Krutetskii (1976) indicated that the Soviets assume that no difference in principle exists in this domain and that any essential difference is explained by tradition, upbringing and education. He has also claimed that attributing female inferiority in mathematics to the sex of the individual can easily be challenged. Social values, selection of students, and education systems should also be considered as well as the fact that males show greater variability in their performance than females.

Differences in achievement are influenced by socio-cultural factors such as attitude toward success in mathematics; stereo-typing of mathematics

as a male domain; perceived attitude of mother, father, and teacher toward one as a learner of mathematics; effectance motivation in mathematics; confidence in learning mathematics; and perceived usefulness of mathematics (Atweh, 1980).

Math Anxiety

Tobias (1976) first indicated that girls were suffering from math anxiety when she hypothesized that persistance rather than ability could account for male-female differences in mathematical performance. Ernest (1976) argued that social processes discourage females more often than males from excelling in mathematics. Weissbrod and Yates (cited in Tobias & Weissbrod, 1980) found that girls' expectations of success are related to their sense of themselves as fem[illegible] and that both affect their willingness to persist in mathematics problem solving. Dweck and her colleagues (cited in Tobias, 1980) found that girls more often attribute their failure to lack of intelligence, boys to lack of effort, and Callahan and Glennon (1975) reported a correlation between mathematics achievement and math anxiety. Math anxiety is prominent among ma[illegible]s and females but coupled with social pr[illegible]res, it may result in greater discouragement for females in math related areas (Donably & Tobias, 1977; Fitzpatrick, 1978).

Math anxiety has never been suggested as the only cause of math avoidance, but rather the term was used to describe the panic, helplessness, paralysis, and mental disorganization that arises among some people when they are required to solve a mathematical problem (Tobias, 1980). The discomfort varies in intensity depending on the person, and it may arise from feelings of helplessness in problem solving, lack of out of classroom opportunity to

practice mathematics, role conflict, or unfortunate experiences with a particular mathematics teacher (Tobias, 1978). The relationship between math anxiety and math avoidance indicates that anxiety inhibits work, because in order to avoid the anxiety, the student will stop studying mathematics (Tobias, 1980). Math anxiety is a predictor of college women's choices, but perceived ability is more predictive of college men's elective decisions.

Math avoiders are often not low achievers in other areas, and their need to achieve may be so high that they will not risk failure and are convinced that no amount of effort will make them competent in mathematics. A dibilitating anxiety may prompt females to grasp at a problem solution before a thorough consideration of the alternatives (Tobias, 1978). Sex related differences in ability/achievement reported in many studies tend to appear at higher grades at the same time that the avoidance phenomenon is observed (Atweh, 1980).

Confidence in one's ability to learn mathematics constitutes a critical dimension in explaining sex related performance in mathematics (Fennema & Sherman, 1978). Suydam (1979) pointed out that fear of mathematics is accepted as normal in society, and there are a disproportional number of mathematics anxious females. The negative messages to girls concerning attitudes and anxiety toward mathematics seem to start at home. In two schools studied, boys perceived their father's and mother's encouragement for their children's mathematical talent in them more than in girls (Fennema & Sherman, 1978).

Anxiety about learning mathematics has been shown to be more highly correlated with mathematics achievement than any other attitudinal variable

(Sherman & Fennema, 1978), and males, more than females, perceive mathematics as a male domain (Fennema, 1977).

Attitudes

Research has provided evidence that negative attitudes toward math are prominent among males and females (Neale, 1969). Attitudes toward math have been found to correlate with math achievement, friend's attitudes toward math, desired math education by parents, teacher's attitudes toward math, self confidence, and intent to study math (Aiken, 1970, 1972, 1976; Dunlap, 1976; Hilton & Berglund, 1974; Keeves, 1975; Merkel-Keller, 1977; Phillips, 1973; Robitaille, 1976; Sherman & Fennema, 1977). However, Fennema and Sherman (1977a) found no evidence to support the claim that negative attitudes affect mathematical achievement. Studies by Boswell (1979), Norman (1977), and Capps and Cox (1969) provided evidence that negative attitudes toward math were not prominent among females. Merkel-Keller (1977), Ernest (1976), and Jacobs (1978) found no sex related differences in attitudes toward math. However, Ernest suggested that negative attitudes coupled with social pressures and career motivation could account for negative attitudes affecting females more than males.

The most significant factor that distinguishes between girl's and boy's attitudes toward mathematics is girl's lower estimation of their own ability. There is some indication that a girl's relative success in mathematics is related to her refusal to regard mathematics as part of a masculine intellectual domain (Badger, 1981). If society deems that science, mathematics, and mechanical activities are the province of males; whereas, literature, languages, and social studies are the province of females, these judgments

will be reflected in the amount of effort expended by girls and boys on these subjects.

Many social changes in the role of women have occured during recent years that may have narrowed the gap between the attitudes of males and females toward mathematics. The prediction of success in mathematics for girls from attitudinal measures is better than that of boys (Atweh, 1980).

Male-Female Differences

There are fundamental differences in the growth and maturity of males and females. Sherman (1971) concluded her study by noting that "women begin life with cells that are fundamentally different from men. In the course of development, this causes antomic differences and other differences as well" (p. 288). Males and females have different hormones and endocrines, and the hormones may also influence the nervous system as well as temperament. Compared with boys, there is a delay in a girl's development of an independent self (Bardwick, 1971).

Given general achievement tasks, there is no consistent sex difference in the degree to which success is attributed to either internal causes or external causes; however, the most consistent difference is that females are more likely to attribute their failures in mathematics to lack of ability than males (Parsons, 1981). While both males and females identify both effort and ability as important causes of mathematics achievement, they differ slightly in the relative importance attached to each of these causes; boys rate mathematical ability to be a more important cause of success and lack of ability as a less important cause of failure than do girls.

Attributions, according to Parsons (1981), play a critical role when a

child confronts a novel set of tasks for which he/she has not yet formed a stable self concept of ability. Developmentally, these results suggest that attributions may play their most important causal role much earlier than high school when self and task concepts are first emerging. Girls seem to see consistent effort, skill, and knowledge as more important determinants of success than do boys (Parsons, 1981); however, girls do not have lower future expectancies and see future math courses as more difficult than boys.

Males tend to be more responsive to competitive situations than females, but not necessarily to a higher level of achievement motivation. While males achieve that motivation by mastery, the effectance of females is contingent on eliciting help from others. This hypothesis confirms the belief that females are trained to aim to please. The characteristics that are logically associated with achievement, such as independence, assertiveness, competitiveness, and agressiveness are in direct conflict with societal expectations of feminine behavior (Atweh, 1980).

Ernest (1975) showed that students in the primary school tend to be competitive on the basis of sex. Each group asserted that they were better in mathematics than the other group. In the secondary school, both boys and girls thought that boys are better in mathematics. All teachers expected their male students to do better in mathematics, teachers were more likely to call on a male volunteer to answer questions than females, and higher order questions were asked twice more frequently to males than to females. More boys received encouragement, feedback, and teacher initiated individual help.

Girls have been found to have less confidence in their ability to

achieve in mathematics and to perceive themselves with less mathematical ability than boys (Crandall, Kathousky, & Crandall, 1965; Fennema, 1977; Kaminsky et al, 1976; Maccoby & Jacklin, 1974; Sherman, 1976; Allen & Chambers, 1977). Girls tend to under rate their ability for success in mathematics, while boys tend to over rate their ability (Boswell, 1979; Fennema, 1974c; Robitaille, 1976), and females do not have as high success expectations in math as do males (Parsons, 1976). Also, females tend to lack positive self concepts when compared to males (Smith & Self, 1977). Callahan and Glennon (1975) found the lowering of self concepts in girls begins to occur at about the same time that sex differences in mathematics become evident. Girls are more conforming and dependent on favorable opinions than boys (Tobias, 1978), girls who are more susceptible to peer influences do not achieve in mathematics as well as girls who are less susceptible (Fitzpatrick, 1978), and girls who do not perceive math as masculine have less conflict (Donably & Tobias, 1977).

Undoubtedly, differences in self concept, competitiveness, confidence, attributions, development, and expectations contribute to differences in mathematics achievement between males and females.

Alleviating the Differences

"Girls need more mathematics and are capable of dealing with more mathematics than is currently available to them" (Atweh, 1980, p. 58). Probably the most basic accomplishment within the last few years has been the awareness of the problem by the mathematics community. Sufficient information about the problem, sufficient commitment on the part of those involved, and time for action is needed before change can take place. Burton's model for

change indicates that one must get in touch with his or her feelings about the issues under consideration, and one must act in such a way as to bring about a solution. This model includes thinking, feeling, and doing components (Burton, 1978). The whole educational and social structure must be prepared to accept some changes in attitude and expectation of girls in mathematics and related fields, because the unfriendly environment has contributed to girl's decisions not to study mathematics (Atweh, 1980).

The family can promote non-sexist child rearing by taking positive steps to enhance it, providing daughters with toys, games, and activities that would develop their spatial and logical abilities, emphasizing the need for mathematics, realizing that more careers are requiring mathematics backgrounds and that this trend will continue to increase (Atweh, 1980).

Teachers, who are considered the decisive force, must present a positive model by feeling good about mathematics and their ability to teach without underestimating the ability of a single individual or having a preconceived idea about their expected performance. Teachers must also be able to provide role models for students by calling attention to successful women in the field of mathematics and related professions. Teachers should be aware of possible sexism in textbooks and materials, increase the content of geometry in their teaching, and attempt to develop confidence of girls in studying mathematics (Atweh, 1980).

The best predictor for the mathematics plans of high school students is their attitude about the usefulness of mathematics for their future lives (Pedro, Wolleat, Fennema, & Becker, 1981). This finding emphasizes the importance of providing all middle and early high school students with infor-

mation on the relationship between mathematics and post high school career choices and educational options. Since females, as a group, perceive mathematics as being less useful to them, programming should ensure that information on the usefulness of mathematics is presented to students in both female-specific and general formats. Emphasis must be placed on the application of information to females as the facts and options are presented to them.

Teaching students to make realistic attributions about their successes and failures has been shown to modify students' confidence levels in other academic areas (Dweck et al, 1978). There are indications that similar interventions designed to reduce mathematics anxiety are also effective (Hendel & Davis, cited in Pedro et al, 1981).

Those who treat math anxiety teach coping techniques as well as mathematics, and those who use a math instructor and a counselor, the latter serving as a coping model, are perhaps using modeling strategies (Meichenbaum, cited in Tobias & Weissbrod, 1980). Horner's theory (cited in Tobias & Weissbrod, 1980) that in a predominantly male vocation females fear success and may even benefit socially from failure has inspired other techniques. Still others employ a habit breaking model designed to make the victim of math anxiety aware of the secondary gains she is deriving from her disability.

There is no typical technique used in the anxiety workshops, but there is a common goal of changing the classroom atmosphere from one of tension and competition to one of trust. The traditional teacher student relationship is being replaced with a relationship that includes relative equality

among leaders and participants (Tobias & Weissbrod, 1980). Although learning mathematics remains the ultimate goal, which includes replacing debilitating habits with self instruction and self encouragement. Self awareness is an important component in the intervention strategies.

Another type of intervention provides the learner with a positive mathematics experience. Weissbrod and Adams (cited in Tobias & Weissbrod, 1980) allow members of their groups to make up their own syllabus in a course on overcoming math anxiety. At Stephens College, Stuth and Prosser-Gelwick prepare one math lesson for each session, but allow the groups to work on something else if they prefer. To eliminate the continuing and disabling effects of earlier experiences, Donady and Auslander (cited in Tobias & Weissbrod, 1980) have collected a number of math problems and exercises through which the student is invited to re-experience past failure and humiliations before the group or while writing a math diary. This strategy assumes that it is the interpersonal dimension of mathematics that is at issue in math anxiety and not mathematics itself. These interventions seem to show that previous socialization can be reversed and that even those with severe anxieties can learn math (Tobias & Weissbrod, 1980).

Although spatial visualization has been found to correlate highly with performance, this does not imply a causal relationship. This influence is a mutual one, for practice and experience in space related activities have been found to increase both mathematics and spatial scores. Yet girls, on the whole, do not participate in these activities, and then their performance suffers as a result, because whatever potential does exist is affected by training and experience (Badger, 1981).

Since the skills of spatial orientation and visualization do appear to contribute meaningfully to predicting mathematics achievement, the trainability of visual skills must be considered as a possible way of alleviating female mathematics deficiencies. Blade and Watson (cited in Connor & Serbin, 1980) reported the effects of training on visual spatial ability after one year's experience in engineering school on performance on the College Entrance Examination Board Space Relations Test; however, sex differences were not reported in this study in response to training.

The effectiveness of a more systematic visual spatial training program is described by Brinkmann (cited in Connor & Serbin, 1980). Brinkmann developed a short course in elementary geometry emphasizing visual spatial problem solving and using programmed instruction techniques. The conclusion was that "girls can at least hold their own when provided with the opportunity to learn something about a particular area in which they are assumed to possess less ability" (p. 941).

Less structured approaches to visual spatial training were adopted by Ciganko and Rennels (cited in Connor & Serbin, 1980). Ciganko's results showed significant and similar increases on the Spatial Relations part of the Multiple Aptitude Test from pretest to posttest, and Rennels results showed a greater improvement from pretest to posttest on standard measures of visual spatial ability. Students receiving analytic training showed a greater improvement than students receiving the synthetic method.

Studies indicate that visual spatial ability is trainable at a variety of levels. Beneficial effects of training have been found in elementary school children, junior high school students, and college students. Such

procedures have been found effective with students relatively high in visual spatial ability as well as with students relatively low in visual spatial ability (Connor & Serbin, 1980). Three studies have found that the training and/or practice effects are relatively stronger for females than for males (Connor, Schackman & Serbin, 1978; Goldstein & Chance, 1965; cited in Connor & Serbin, 1980).

Spatial visualization may be a more difficult skill to teach than spatial orientation, and there often is no indication in studies that females profit more from training than males. These findings do suggest that the sex which is performing less well without training is likely to benefit more from training (Connor & Serbin, 1980). The Differential Aptitude Test (DAT) is a relatively consistent discriminator of male and female performance, but other measures do not yield sex related differences consistently at all. The Space Relations section of the DAT is the visual spatial test most widely used for vocational guidance to high school students and for admission selection of students to technical programs such as engineering and denistry. This implies that the use of this visual spatial test may have a more negative effect on females pursuing careers in technical fields than would be the case if a different visual spatial test or several were used more widely (Connor & Serbin, 1980). Also, the DAT which is thought to be a measure of both spatial orientation and visualization showed a training effect. The training results with the other tests suggest the possibility that scores on this test were elevated as a result of students' improvement in spatial orientation rather than visualization skill.

Treagust (1980) suggested that by focusing on curriculum materials that

include the learning processes that are missing from each individual student's repertoire, teachers can help minimize gender differences in spatial ability. A student with poorly developed spatial abilities should be taught primarily by verbal means but should be presented with activities that will improve spatial skills. Treagust also suggested that males and females should be taught in more similar ways in an attempt to reduce the differences in spatial abilities and ensure comparable opportunities between the sexes in higher education and in employment. Males and females should receive comparable education in science and math subjects as well as in subjects such as technical drawing to promote female preparation and interest in such fields as science, engineering, and architecture, which require a high degree of spatial ability (Treagust, 1980).

The efficacy of training related to spatial ability appears to be a function of the criterion test, with visualization less amenable to teaching than disembedding or spatial orientation, and few training studies have paid attention to the crucial matters of retention and transfer on which judgments of efficacy depend (Badger, 1981).

Conclusions and Recommendations

Since the study of and achievement in mathematics has a filtering effect, the improvement of the status of women in the workforce necessitates that more females study and achieve more in mathematics. At the same time, members of society are expressing more anxiety and avoidance to the study of mathematics which coincides with the trend of mathematics becoming more essential for participating and succeeding in many careers and professions. Females avoid the study of mathematics more, have more negative attitudes

toward the study of and achievement in mathematics, and are then unable and unqualified to compete for many high status vocations and professions, and unless some meaningful action is taken, the present conditions will continue to prevail.

Males and females are different! Males and females do not have the same experiences with respect to the study of mathematics, and males and females differ in spatial ability, math anxiety, attitudes toward math, amount of math studied and social pressures. Improvement in the mathematics achievement of females can be accomplished by increasing the awareness of parents, teachers, and students to the problem itself and the various causes which contribute to the female deficiences. A single answer or solution does not exist, but a coordinated effort in reducing math anxiety, improving attitudes, alleviating difficulties in spatial ability, increasing female enrollment in math classes at more advanced levels, and a continued interest in alleviating sexual social biases will increase mathematics achievement. The mathematical talents and potential of half the population is unknown and untapped, and the future of females, and society in general, can be enhanced by addressing these problems and needs with emphasis on the contributions that will result and the opportunities that will be made available.

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